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Management of Lakes Through Sediment Removal

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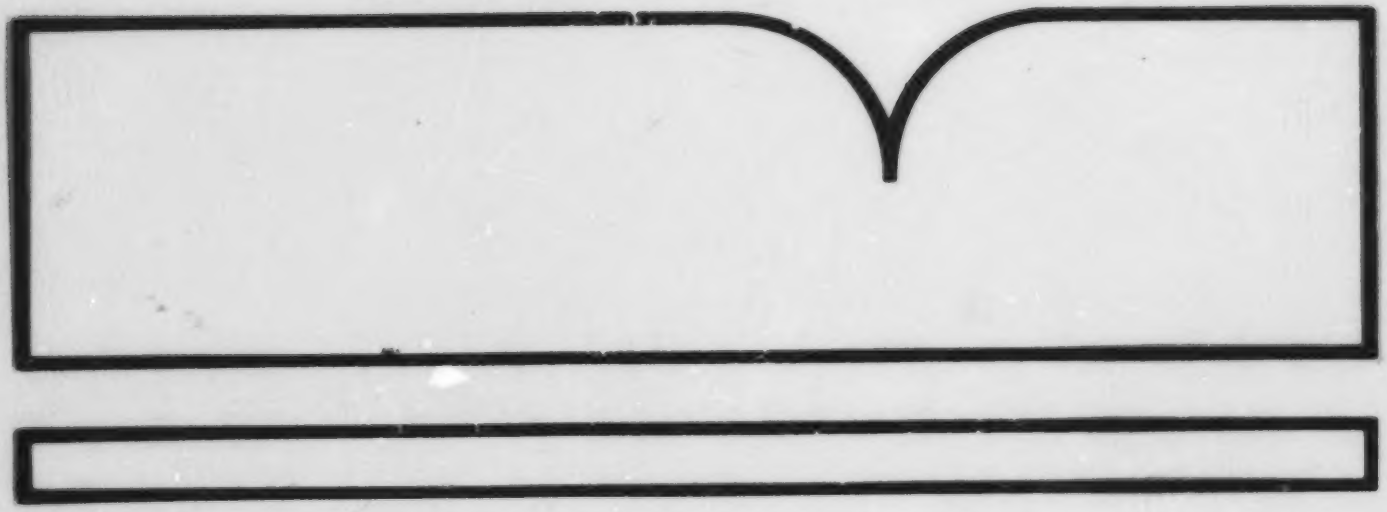

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MANAGEMENT OF LAKES THROUGH SEDIMENT REMOVAL

by

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16. ABSTRACT

When properly conducted, sediment removal is an effective lake management technique. This paper describes: 1) the purpose of sediment removal, 2) environmental concerns, 3) depth of sediment removal, 4) sediment removal techniques, 5) suitable lake conditions, 6) exemplary case histories, and 7) costs.

The reasons for dredging lakes are to deepen, limit nutrient recycling, reduce macrophytes, and to remove toxic substances. Case histories of lake dredging projects to date reveal that while some adverse impacts to the lake do occur during dredging, most are of short duration and the end result warrents the short term impacts.

There is little doubt that dredging can be a successful lake restoration technique if the project is properly designed and implemented. Successful examples of both surface sediment skimming and deep (6 to 8 m) dredging can be cited. Emphasis should be placed on prpoer pre-treatment evaluation and execution of thorough implementation plans.

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MANAGEMENT OF LAKES THROUGH SEDIMENT REMOVAL

When properly conducted, sediment removal is an effective lake management technique. This paper describes: 1) the purpose of sediment removal, 2) environmental concerns, 3) depth of sediment removal, 4) sediment removal techniques, 5) suitable lake conditions, 6) exemplary case histories, and 7) costs.

PURPOSES OF SEDIMENT REMOVAL

When recreational activities are impaired due to shoaling, the only practical means of restoring lake use is to deepen it through sediment removal. The intended lake use, availability of dredge material disposal area, and available funds must be considered in the design of a lake deepening project. The reasons for deepening and the means of measuring the success of such projects is the most straightforward of the sediment removal objectives. The efficiency of modern dredging equipment being what it is, it is little wonder that in 1970 Pierce indicated all lake dredging projects undertaken for the purpose of deepening were successful.

Shallow eutrophic lakes frequently are susceptible to periodic influx of nutrients from the sediment. These inputs of phosphorus and nitrogen occur most often during peak recreation periods. They usually result in algal blooms and are thus an annoyance to users.

Welch *et al*. (1979) estimated phosphorus inputs to Long Lake, Washington were 200-400 kg yr^{-1} or about 25-50% of the external loading. Shagawa Lake, Minnesota experiences summer internal phosphorus pulses of approximately 2000-3000 kg during June, July, and August. This represents about 66% of the total annual phosphorus loading. Sediment recycled phosphorus in Shagawa Lake has been sufficient to produce large summer algal blooms, thus reducing its predicted rate of recovery following advanced wastewater treatment at the City of Ely (Larsen *et al*., 1981).

The above indicates phosphorus loading from sediment constitutes a significant portion of total phosphorus loading in some lakes. Therefore, sediment removal might be expected to reduce the rate of internal nutrient recycling, thus improving water quality for recreational purposes.

Toxic substances are becoming a common concern among industrialized nations. Insufficient treatment and disposal practices of the past have materialized into today's problems. Large scale surveys and improved

analytical techniques are demonstrating that toxicants are more common to freshwater sediments than previously suspected (Horn and Hetling, 1978; Matsubara, 1979; Bremer, 1979). Many of the toxicants recycle from the sediment to the overlying water column where they may be bioaccumulated by aquatic organisms. Perhaps the most infamous incident of this type was the mercury pollution of Minimata Bay, Japan in 1956 (Fujiki and Tajima, 1973). More recent incidents in the United States have involved kepone contamination of the James River, Virginia (Mackenthun et al., 1979) and PCB contamination of Waukegan Harbor, on the Great Lakes (Bremer et al., 1979).

Removal is the most obvious solution to the problem of contaminated sediments. However, removal frequently is complicated by secondary pollution of the overlying water column due to sediment agitation during the removal process. Cutterhead hydraulic dredges can remove large volumes of sediment, but unfortunately they can also resuspend large volumes of fine sediment (Suda, 1979; Barnard, 1978). Resuspension of sediment while dredging toxic substances must be minimized to prevent potential environmental damage. Therefore, proper selection of equipment becomes important to the success of toxic sediment removal.

Rooted aquatic plants may interfere with fishing, boating, and swimming activities. An overabundance of these plants may also be aesthetically displeasing. Beyond this a large biomass of plant material may produce adverse oxygen conditions due to respiration in the littoral zone during hours of darkness. In addition, there is an increasing literature on the effects of macrophytes on internal nutrient cycling. Their role in this process, with its effect on algal dynamics, may be an important reason for attempting to control macrophytes by removing them from a lake. Wetzel (1975) indicates that most of the organic matter found in small lakes may be derived from their littoral zone. A number of other researchers have documented that various species of freshwater aquatic plants extract nutrients chiefly from the sediment and translocate them to the surrounding water (Schults and Malueg, 1971; Twilley et al., 1977; Carignan and Kalff, 1980).

Barko and Smart (1979) estimated that in-lake mobilization of phosphorus by Myriophyllum in Lake Wingra, Wisconsin, might amount to approximately 60% of the annual external phosphorus loading. Welch et al. (1979) indicated that much of the "sediment" phosphorus loading in Long Lake, Washington was probably due to rapid plant die-off and decay. Current information indicates that any long range lake restoration project concerned with in-lake nutrient controls will need to focus on both macrophytes and sediment (Carignan and Kalff, 1980; Barko, 1980).

ENVIRONMENTAL CONCERNS

There are a number of potential environmental problems associated with sediment removal. The problems generally can be classified according to in-lake and disposal area types. In-lake problems commonly center around the resuspension of sediment during its removal by dredge. One of the most common problems is the liberation of nutrients. Phos-

phorus is of particular concern due to its high concentration in interstitial waters of eutrophic lakes. Dredge agitation and wind action tend to move dredge-disturbed nutrient-laden sediment into the euphotic zone of the lake, creating the potential for algal blooms. Dunst (1980) found increased algal production in Lilly Lake, Wisconsin, when hydraulic dredging began. It was short-lived, however, and never posed a nuisance level problem. It appears that nutrient enrichment due to dredging can be real, but that in most cases the short-term impacts relative to the long-term benefits will be negligible.

Toxic substances in sediments may be a major concern. Although small lake, sediment removal projects for the purpose of removing toxic substances have been relatively uncommon, there is a growing concern (Matsubara, 1979; Sakakibara and Hayashi, 1979; Bremer, 1979; Spencer Engineering, 1981). The major problem associated with toxicants and resuspended sediment centers around fine particles. Murakami and Takeishi (1977) have shown that up to 99.7 percent of the polychlorinated biphenyls (PCB) associated with sediment is attached to particles less than 74 μm in diameter. This could become a problem in freshwater dredging projects where particle settling times are significantly greater than for marine waters. Therefore, special precautions including dredge types and/or disposal and treatment techniques should be considered (Matsubara, 1979).

A relatively common concern with lake dredging projects is the destruction of the benthic community. If the lake basin is dredged completely, two to three years may be required to reestablish the benthic fauna (Carline and Brynildson, 1977). However, if portions of the bottom are left undredged the reestablishment may be almost immediate (Andersson et al., 1975; Collett et al., 1981) or within one to two years (Crumpton and Wilbur, 1974). In any case, the effect on benthic communities appears to be short-lived relative to the longer term benefits derived. The same appears to be true for game fish populations (Carline and Brynildson, 1977; Spitler, 1973).

The major non-lake impact of sediment removal concerns the dredged material disposal area. Locating a disposal site for urban projects is a major problem. Section 404 of Public Law 92-500 prohibits the filling of any wetland area exceeding 4.0 ha (10 acres) without a Federal permit. Thus, low lying areas which in the past were commonly filled are more difficult to obtain permits for if they are available at all. The flooding of wooded areas with dredge disposal material should be discouraged. Flooding kills trees providing unsitely evidence of an improper disposal plan.

A frequently used disposal method in recent years employs diking in upland areas. A not uncommon problem with these sites is dike failure and associated destruction of adjacent areas (Calhoun, 1979). Groundwater contamination may become a problem with upland disposal if sand or gravel underlies the disposal area. Water wells in these areas could become contaminated, potentially adding liability to the sediment removal project.

Another problem not uncommon to lake dredging is underdesign of disposal area capacity. Unfortunately, these failings usually become apparent only after the project is fully operational. The problem may be associated with the slow settling rate of suspended sediment in freshwater (Wechler and Cogley, 1977). As disposal areas begin to fill, their ponding depth is reduced and so is their efficiency to retain suspended solids. This may result in failure to meet discharge permit requirements. If that happens there are but two choices: shut-down until seepage and evaporation allow additional filling, or treat the discharge water. Either alternative means additional expense to the project. Disposal area designs must be formulated for end of project efficiency, not average discharge requirements over the entire project. Palermo et al. (1978) have summarized important technical information that will assist with the proper design, construction, and maintenance of dredged material disposal areas. Barnard and Hand (1978) describe when and how to treat disposal area discharges if standards cannot be met. Other reports by Brannon (1978), Chen et al. (1978), Gambrell et al. (1978) and Lunz et al. (1978) provide valuable information that will help minimize environmental problems at disposal sites.

SEDIMENT REMOVAL DEPTH

When restoring a lake for sailing, power boating, and associated activities, the deepening requirements are relatively straightforward. However, when deepening to control internal nutrient cycling and macrophyte growth, the criteria are less clearly defined.

Lake Trummen, Sweden, is perhaps the most thoroughly documented case history of sediment removal to control internal nutrient cycling. Sediment removal depth in Lake Trummen was determined by mapping both the horizontal and vertical distribution of nutrients in the sediment. Digerfeldt (1971), as referenced by Bjork (1972), determined that approximately 40 cm of fine surface sediment accumulated from 1940 to 1965. Aerobic and anaerobic release rates of $PO_4^{=}$-P and NH_4^{+}-N from this surface layer were markedly greater than for the underlying sediment. Based on these differences a plan was developed to remove the upper 40 cm of sediment.

Another approach to determining sediment removal depth has been proposed by Stefan and Hanson (1979). Their approach is similar to that developed by Stauffer and Lee (1973) which described thermocline erosion by wind in northern temperate lakes. Stefan and Hanson (1979), have used their model to predict the depth to which a lake must be dredged to maintain stable summer stratification.

The Stefan and Hanson (1979) model assumes stable summer stratification is necessary to prevent enriched hypolimnetic waters from mixing into the epilimnion. Based on that assumption they calculated that Hall Lake, Minnesota, would require dredging to a maximum depth of 8.0 m. Dredging volume to obtain the 8.0 m depth would be enormous given the lake's current 2.25 km^2 surface area and 2.1 m mean depth.

There is no apparent chemical/physical distinction between shallow and deep sediments in Hall Lake. Phosphorus concentration is relatively uniform from the sediment surface to a depth of 8.5 m. However, it is possible that the phosphorus release rates from deeper sediment could be less than those of surface sediments. If that were the case for Hall Lake, surface sediment skimming might produce nearly the same result as deep dredging and at a considerable saving. Therefore, it seems advisable to conduct nutrient release rate experiments prior to adopting a lake temperature modeling approach to determine dredging depth for nutrient control.

Dredging will remove rooted macrophytes from the littoral zone of lakes, but there have been few detailed studies to determine depths necessary to prevent plant regrowth. Factors influencing the areas in which rooted macrophytes grow include temperature, sediment texture, sediment nutrient content, and light level.

Using information developed by Belonger (1969) and Modlin (1970), the Wisconsin Department of Natural Resources developed a guide to prescribe dredging depths necessary to control the regrowth of macrophytes. The guide was developed by regressing the maximum depth of plant growth in several Wisconsin lakes against their average summer water clarity (light level via Secchi disk). The relationship is described by the equation:

$$Y = 0.83 + 1.22X$$

where,

Y = maximum depth of plant growth (meters)
X = average summer water clarity (meters)

According to Dunst (1980) the above relationship is used as a rough guide to develop dredging plans for macrophyte control. Dunst indicated, however, that dredging depths need not always exceed the predicted Y-value to achieve control. He indicated further that slight deepening frequently changes plant speciation to less objectionable forms.

Hutchinson (1975) while describing the work of Maristo (1941) stated "The maximum depth at which autotrophic plants can grow, irrespective of their nature, clearly does depend on the transparency of the water." The reliability of this relationship could be determined simply by regressing maximum depth of summer plant growth for several individual lakes against average summer Secchi disk transparency and determining the correlation coefficient.

SEDIMENT REMOVAL TECHNIQUES

There are two basic types of lake sediment removal practices. The first is the land based technique which employs buckets, or clamshells operated by mechanical dragline from the shore. A variation of the same technique is lake drawdown or dewatering followed by bulldozer excavation in the lake basin.

One advantage of bucket or clamshell dragline operations is their ability to remove hard sediment at in situ density. A second advantage is their mobility from one location to another since most are truck transportable track-mounted units. Beyond these two factors most aspects of dragline use for lake sediment removal are negative. One of the greatest limitations of the dragline is its short reach, commonly no more than 20 to 40 m. A second disadvantage is the rough, uneven bottom configuration normally created in hard sediment by dragline buckets. The sediment production rate for draglines is relatively low because of their bucket swing, drop, close, retrieve, lift, and dump operation cycle. Dragline operations commonly create very turbid water conditions.

Some of the problems mentioned above can be overcome by using silt curtains. The silt curtain consists of a continuous polyethylene sheet (skirt) buoyed at the surface and weighted at the bottom so it hangs perpendicular to the water surface. It may be used to isolate a length of shoreline where draglines are being operated or to encircle an open water dredging operation (Figure 1). The purpose of the silt curtain is to isolate turbidity conditions within the immediate dredging area, thus protecting adjacent clean water areas. Silt curtains, while effective in controlling surface turbidity, are open at the bottom and will permit the escape of turbid water near the sediment water interface.

Another means of minimizing turbidity from grab or bucket type dredging operations is to use a covered, watertight unit (Figure 2). These watertight buckets are manufactured in sizes ranging from 2 to 20 m^3. The manufacturer claims turbidity reductions from 30 to 70 percent compared to open buckets of comparable size. Dredged material production using watertight buckets is cleaner than conventional buckets, but still relatively inefficient compared to hydraulic dredges.

Lake drawdown or dewatering, a preliminary step to bulldozer excavation, usually is restricted to artificial lakes having outlet control structures. Water level in these reservoirs can be lowered easily exposing a large portion of the basin. After proper drying, sediment is scraped from the basin with earthmoving equipment. Apparent drying of lake sediments can be deceiving. Although they become crusted and cracked at the surface, they frequently are fluid and soft underneath. Pierce (1970) pointed out that the drawdown and bulldozer technique may be accomplished most effectively in cold climates, during the fall or winter when the sediment is frozen. An added incentive for this is that total expenses may be reduced by employing equipment operators during the off season. Fall and winter treatment would also minimize recreational use impairment.

The limitations of dragline operations and the problems of dewatering natural lakes leads to the second basic approach to sediment removal, the use of floating equipment. The simplest type of floating equipment is a clamshell or bucket dredge mounted on a barge. This type of dredge is used most frequently in removing "hard-pan" material and is not employed commonly in small lake dredging. This configuration has

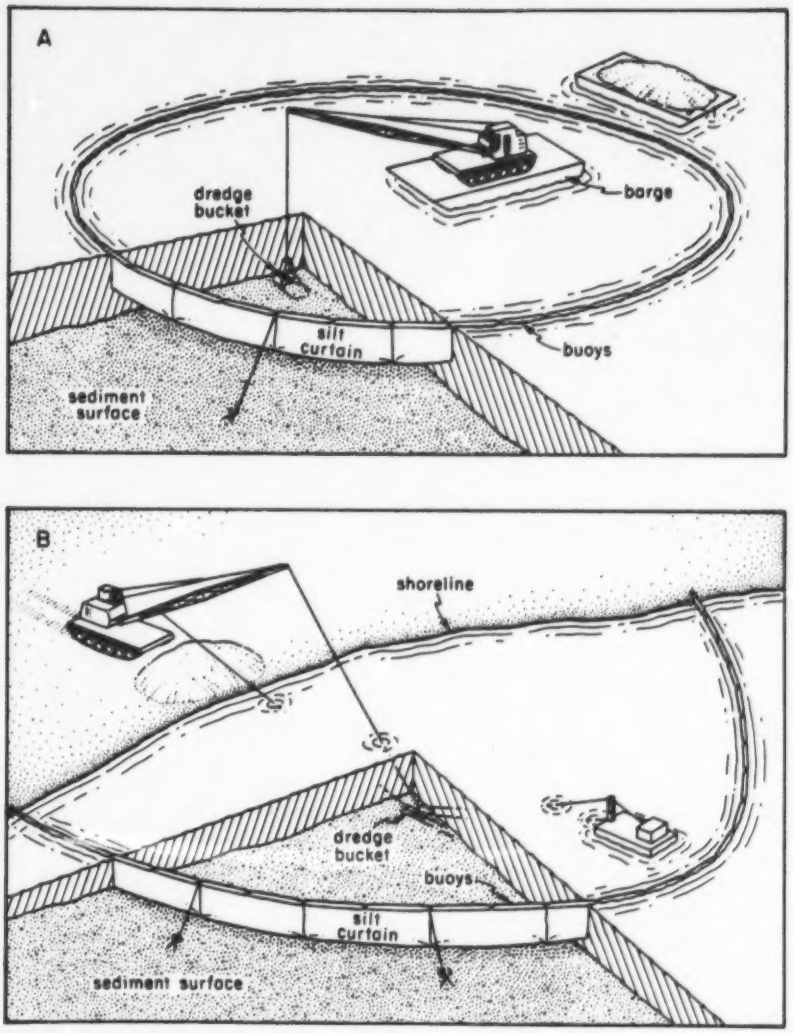

Figure 1. A) Silt curtain encirclement of an open water clamshell operation.

B) Shoreline isolation of a bucket dragline operating using a silt curtain.

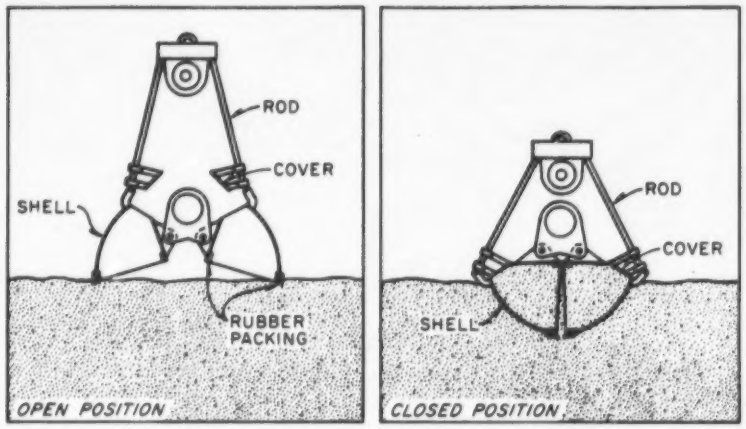

Figure 2. Open and closed positions of the watertight bucket redrawn from Barnard (1978).

the same shortcomings as its land based counterpart in terms of production efficiency and turbidity. Floating clamshell operations are frequently encircled by silt curtains to minimize turbidity. Although their operating cycles are somewhat inefficient relative to hydraulic dredges, they can be very effective where underwater logs, stumps, or boulders might be encountered. These conditions frequently are found in reservoirs.

Hydraulic dredges include hopper, dustpan, and cutterhead systems. Hopper dredges typically are large ocean-going vessels used for maintaining stream channels and harbor areas on large lakes. They are impractical for small lake use.

Dustpan dredges employ wide vacuum cleaner like heads with a series of high velocity water jets to loosen the sediment. Suction heads of a dustpan dredge are typically oriented upstream so that material broken up by the water jets flows into the pickup head in a fashion similar to the sweeping of debris into a dustpan. From there it is taken up by suction from the pump and discharged through a pipeline to a disposal area. Dustpan dredges usually are large non-portable apparatuses and thus not readily employed in lake restoration. However, Pierce (1970) indicated the dredge used at Greene Lake, Washington, in 1961-62 was a unique variation of a dustpan dredge. The apparatus described by Pierce was an extremely simple, but apparently efficient, one which removed 9.17×10^3 m^3 of sediment from the lake. The positive experience at Greene Lake indicates that dustpan or modified dustpan dredging practices may warrant further examination for freshwater lakes.

Inland lake sediment removal is most commonly accomplished with a cutterhead hydraulic pipeline dredge. This type of equipment has become the workhorse of the dredging industry and has become relatively common to inland lake dredging projects with the advent of small portable equipment. The primary components of any cutterhead dredge system include: 1) the hull, 2) the cutter head, 3) the ladder, 4) the pump, 5) the power unit, and 6) the dredged material distribution pipe (Figure 3A).

Sediment loosened by the cutter moves to the pickup head by suction from the pump. The sediment slurry, typically 10 to 20 percent solids, is discharged to a remote disposal area by pipeline. Diameter of the discharge pipe describes the nomenclature of cutterhead dredges. Figure 3B shows how the cutterhead is swung from side to side by pulling alternately on the port and starboard swing wires. Forward movement of the dredge is accomplished by alternately raising and lowering spuds at the stern.

Portable dredges for lake use are essentially miniatures of the large cutterhead dredges that have been used in coastal construction and harbor maintenance work for years. Consequently, they are probably not as efficient as they might be, if modified specifically to handle lake sediment which is highly viscous and commonly contains 40 to 60 percent organic materials.

Modern hydraulic dredged can move large quantities of sediment. One reason for this is that they are not confined to near-shore operations. Another reason is their continuous operating cycle. High production rates are not without their negative aspects. Most hydraulic dredge slurry contains 10-20% solids. Stated another way, 80-90% of the slurry volume is water. If the residence time of the disposal area is inadequate to precipitate the solids, discharge permits may be violated. In this event, it becomes necessary to either shut down temporarily or to treat the discharge water. In either case the large water volumes produced by hydraulic dredges might become an added expense. The large pumping capacity of these dredges adds the possibility of an unplanned lake drawdown unless overflow water is returned to the lake.

The amount of sediment supplied to the suction head is controlled by cutter rotation rate, thickness of the cut, and the swing rate (Barnard, 1978). Improper combination of any of these might cause the generation of excessive turbidity. Therefore, not only the configuration of the dredge equipment itself, but the skill of the dredge operator is important to minimizing turbidity.

Portable cutterhead dredges, as mentioned previously, are essentially miniatures of large coastal waterways dredges. The cutterheads of coastal dredges were designed for cutting sand, clay, and silt sediment. They were not intended for use in fine, flocculant organic sediments encountered in lake dredging. Therefore, simple downsizing of the coastal dredge has not been entirely satisfactory for lake dredging projects. Consequently, soft lake sediments have been a challenge to

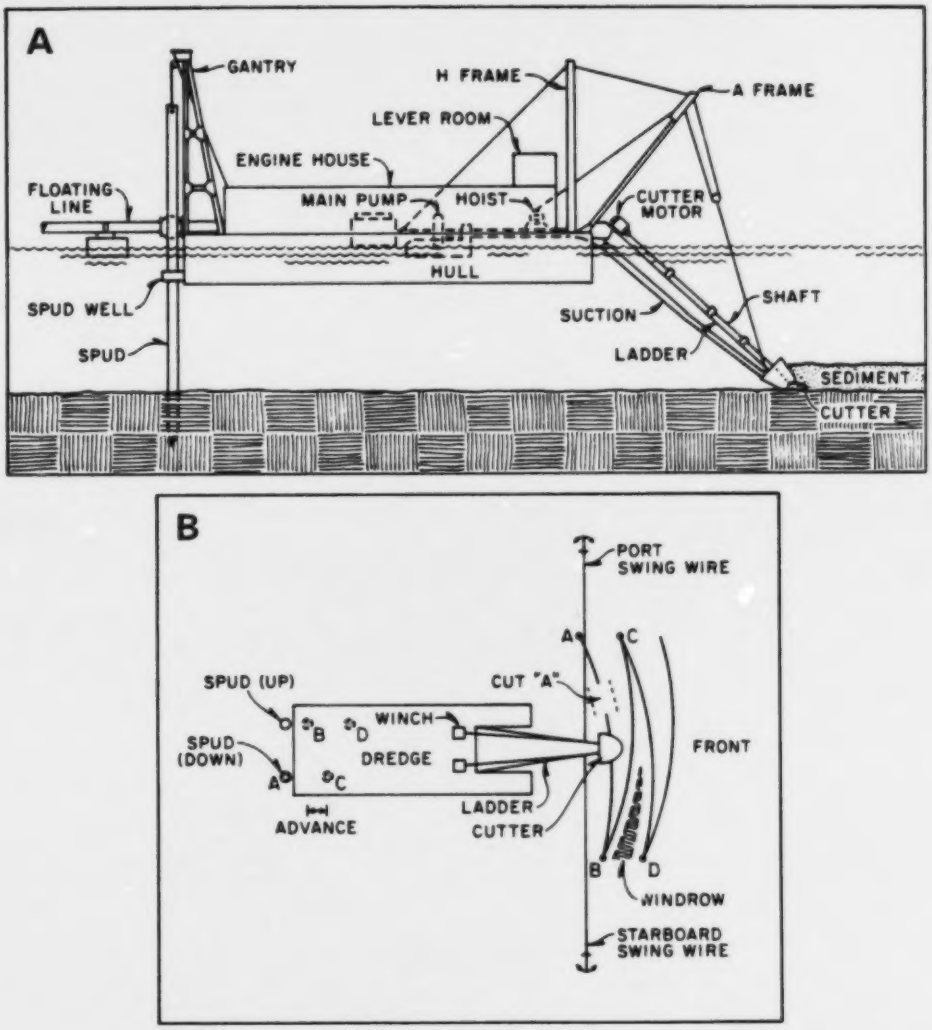

Figure 3A. Configuration of a typical cutterhead dredge. B. Spud stabbing method for forward movement and resultant pattern of cut (modified after Barnard, 1978).

the dredging industry. These fine sediments are easily disturbed and resuspended to the overlying waters by dredging activity. Attempts to deal with this problem has brought several innovations. Among them is the cutterhead design used by Mud Cat®. Mud Cat dredge intakes resemble those of dustpan dredges, but instead of water jets, they use a horizontal auger to dislodge and move sediment to the center of the (2.4 m wide) dredge head where it is sucked up the intake.

Figure 4 demonstrates the high mobility of the small Mud Cat dredges. Note also the mud shield which can be raised or lowered over the auger head to minimize resuspension of sediments. Nawrocki (1974) reported turbidity plumes due to dredging with a Mud Cat machine were confined to an area no more than 6 m distant from the dredge; however, operating conditions were not clearly defined. Suspended solids in the increased turbidity area ranged from 39 to 1260 mg liter^{-1}. Those near the bottom were approximately 1000 mg liter^{-1}. More turbidity is created by forward motion of the dredge than by backwad motion. This appears to be associated with raising the mud shield while moving forward and lowering it when moving backward. Mallory and Nawrocki (1974) indicated the Mud Cat dredge should be capable of producing 30 to 40 percent solids.

The Mud Cat guidance system is well suited to work on small water bodies. The dredge operates on a cable anchored at both shorelines. This permits uniform dredging of the bottom with few missed strips. Mud Cat dredges have been used successfully at Collins Park and several other small lakes in New York State. The portability, guidance system, reduced turbidity, and increased solids content of these dredges appears to make them ideally suited to small lake restoration projects.

There are a few other dredging systems which, although not commonly used on lake dredging projects, deserve mention because of their unique capabilities. Each of these systems was developed specifically for soft, viscous sediment similar to that found in lakes. The machines were originally created on a large scale for harbor maintenance, however, it appears feasible to downsize them for lake dredging, which has been done in some cases (Matsubara, 1979; Spencer Engineering, 1981).

The pneuma dredging system is unique among dredging systems. It was developed in Italy and employs air driven pumps. The system commonly consists of three cylindrical pump bodies, a pickup head, a compressor, and air lines to the pump bodies. This system operates on the principle that sediment and water, under hydrostatic pressure, will be forced into the pump body which is maintained at atmospheric pressure. Therefore, the filling efficiency increases with increased depth (increased hydrostatic pressure). At depths less than 10m, however, hydrostatic pressure is insufficient to operate the system effectively. The Japanese Oozer® dredge system (a modified pneuma system) has overcome the problem of operating at shallow depths by creating partial vacuum in the pump bodies during the filling phase. Partial vacuum in the pump bodies also permits more rapid filling at

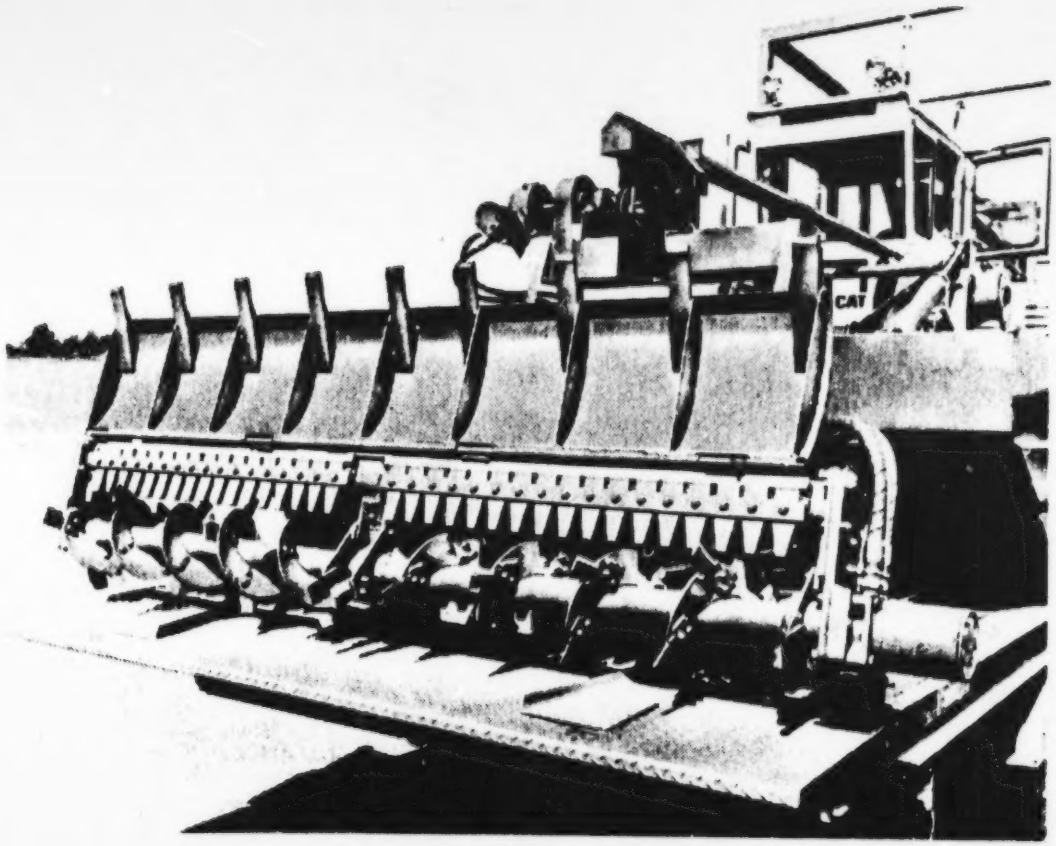

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Figure 4. The mud cat dredge features a unique auger-type cutterhead. Size of the dredge makes it extremely portable (with permission of National Car Rental).

greater depths. Figure 5 is a schematic diagram of the Oozer dredge system. The use of vacuum and air pressure to respectively fill and empty the pump body and drive sediment through the discharge pipe, permits the removal of soft sediment at *in situ* density. This means the solid content of these dredge slurrys may run as high as 70 percent (Koba *et al.*, 1975).

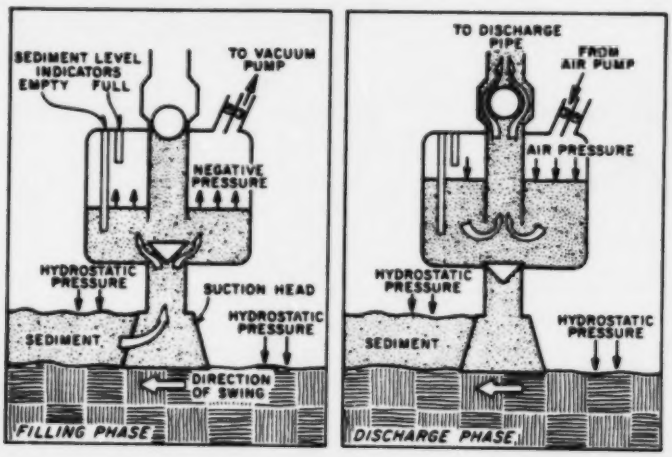

Figure 5. Schematic of oozer dredge system.

High solid content of the dredge material has several advantages, among them is that production rate is relatively high (500 to 2,000 m^3 hr^{-1}), sediment removal at *in situ* density minimizes its resuspension, and far less water volume must be contained at the disposal area.

Another dredge specialized for soft sediment removal is the cleanup system developed by TOA Harbor Works Company of Tokyo, Japan. This system employs a special suction head consisting of an auger, movable plates to direct sediment flow, a floating wing device to contain sediment as it is fed to the auger, and a large gas collection shroud (Figure 6). Methane and hydrogen sulfide gases, frequently liberated from organic sediment during dredging, are collected by the shroud thus preventing foul odors.

The structural configuration of the Oozer and Cleanup dredges are similar to a conventional cutterhead dredge (Figure 3a). Likewise their cutpaths are created by swinging the cutter from port to starboard and vice-versa. The major differences are in the pickup head configuration, the cutter (auger) apparatus, and the pumps. As with most hydraulic cutterhead dredges, the Cleanup System has a large centrifugal pump mounted within the hull. However, in addition it has an auxillary submerged centrifugal pump at the end of the ladder near the pickup head. The combination of pickup head configuration and pump equipment, as with the Oozer System, permits the removal of soft sediment at *in situ* density (20 to 70 percent solids in the slurry according to Sato, 1978).

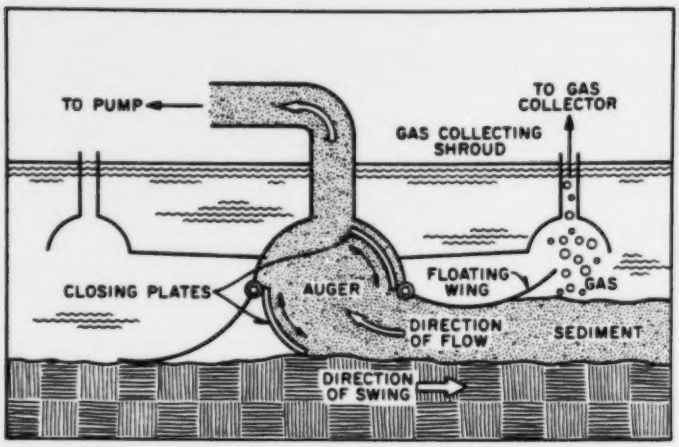

Figure 6. Suction-head of cleanup dredge system.

Both systems were compared with conventional cutterhead equipment to determine their relative ability to minimize secondary pollution from sediment resuspension (Suda, 1979). Suspended solids concentrations 1.5 m above the sediment water interface, and directly over the two special dredge heads averaged 6 to 8 mg liter^{-1}. Under similar conditions the suspended solids concentrations around a conventional cutterhead averaged 40 to 80 mg liter^{-1} at the same depth.

Although the above two specialized dredge systems were developed by the Japanese to remove highly contaminated sediments from large harbors, they demonstrate that extremely soft sediment can be removed efficiently with minimal resuspension if properly designed equipment is employed. A miniature Oozer system has been used successfully to remove polluted sediment from Lake Kasumigaura, Japan (Matsubara, 1979). Also, a Pneuma Pump dredge system was employed recently at Gibraltar Lake, California where mercury contaminated sediment was removed. The major problem encountered with the Pneyma system at Gibralter Lake was poor pump body construction. The entire pump bodies had to be disassembled and re-welded. Also, the rubber in the valving system proved to be a weak point (Spencer Engineering, 1981). After much reworking, the dredge system averaged 500-600 μ3 hr^{-1} production at an average suspended solids concentration of 40-50 percent.

LAKE CONDITIONS SUITED TO DREDGING

When a lake has sedimented sufficiently to be unusable for boating, swimming, and fishing activities, virtually nothing short of dredging will restore these uses. However, the high cost of dredging (Peterson,

1979) dictates that the feasibility of this treatment be examined closely in comparison to the intended use of the lake and alternative treatment methods.

Size of the lake might seem important to determining dredging feasibility. However, size appears not to be a constraint. Peterson's (1979) examination of 64 lake dredging projects found that size ranged from less than 2 ha to over 1,050 ha and that volume of removed sediment ranged from a few hundred m^3 to over 7 million m^3. The mobility of modern hydraulic dredges and their pipeline disposal systems indicate that there are few technological limitations to dredging large inland lakes.

The one aspect of large inland lake dredging that might become limiting is the requirement for a commensurately large disposal area. A dicotomy arises from the fact that restoration is most frequently sought for lakes in densely populated areas where sediment disposal space is most scarce. It is also true, however, that the greatest user benefits will be derived from projects in densely populated areas (JACA, 1980). Therefore, it is important that disposal alternatives be explored for these situations.

Various productive uses of dredged material have been examined by Lunz et al. (1978), Walsh and Malkasian (1978), and Spaine et al. (1978). A practical solution was employed at Nutting Lake, Massachusetts, where approximately 153 x 10^3 m^3 of sediment was sold as a soil conditioner at a price of \$1.40 m^{-3}. This reduced the total dredging cost by \$215,000 and the per unit dredging cost to about \$1.00 m^{-3} (Worth, 1981). The selling and removal of dredged material does not negate the need for a "disposal area," but it may reduce the size requirement of what actually becomes a sediment handling area. A 7 ha, two-basin handling area with a total holding capacity of approximately 98 x 10^3 m^3 was used at Nutting Lake. This area provided sufficient capacity for a season's dredging. Before the next dredging season (summer), the material was removed, sold, and the initial disposal capacity was available once more. In this way, the disposal area need not be permanently dedicated to a fill. The point is that any lake, to be suitable for dredging must be in reasonable proximity to a disposal area, but lack of an area adequate to accommodate all of the dredged material need not hamper a project from going forward.

Sediment removal projects should have reasonable assurance of longevity in order to be cost effective. Therefore, an estimate of sedimentation rates should assist in determining the feasibility of dredging. Although dredging is expensive on a per unit basis of dredged material, when costs are amortized over the life expectancy of the project they may look much more reasonable. Sedimentation rates will help establish this "reasonableness." If all other conditions are similar, lakes with large surface areas, relative to their watershed areas, will probably have lower sedimentation rates than small lakes with large watersheds. Thus, the large lake/small watershed scenario will probably benefit more from dredging than will the small lake/large watershed one.

All of the above factors address physical features, i.e., depth, size, disposal, and watershed area, and sedimentation rate, but what of the chemical aspects of sediment and their influence on lake biota? Current information demonstrates that lakes with highly enriched surface sediments relative to underlying sediment might benefit from shallow dredging (Andersson et al., 1975; Bengtsson et al., 1975). Lake Trummen, Sweden showed marked changes in water chemistry and biota when 40 cm of rich surface sediment was removed (Bjork, 1978). Similar changes were observed in Steinmetz Lake, New York when 25 cm of organic sediment was removed and replaced by the same amount of clean sand (Snow et al., 1980). In both cases, extensive sediment surveys before dredging revealed that surface sediment was disproportinately rich in phosphorus and nitrogen relative to the deeper sediment. Sediment profiles can be developed with the assistance of a Livington piston corer. It will be important to note sediment color and texture differences with depth and to chemically characterize (phosphorus and nitrogen) the surface (0 to approximately 2 in) sediment relative to deeper sediment if nutrient control is the intent (Peterson, 1981). Beyond this it will be quite useful to know the sediment particle size, settling rate, volume, etc. in order to design a disposal area and select the proper dredge. A report by Palermo et al. (1978) provides good guidance for disposal area design and Pierce (1970) offers assistance in selecting lake dredging equipment.

Several variables may determine the suitability of a lake to dredging. However, the lakes most suitable would generally be shallow, have low sedimentation rates, organically rich sediments, long hydraulic residence times, and the potential for extensive use following dredging.

CASE HISTORIES

Dunst et al. (1974) identified 33 United States dredging projects in their "Survey of Lake Rehabilitation Techniques and Experiences." Seven years later Peterson (1981) listed 64 planned, active, or completed projects in this country. No doubt both the 1974 and 1981 listings were incomplete since many small lake dredging projects are completed, but never reported in the open literature. If records are available from these projects they seldom extend beyond the completion date. Therefore, few well documented long-term evaluations are available. The two case histories that follow represent sediment skimming and deep sediment removal techniques. They are both considered to be successful at this time and have ample documentation to demonstrate that success.

It should not be construed from the following presentations that all dredging projects to control internal nutrient recycling are successful. On the contrary, there have been numerous failures. However, almost all failures or marginally successful projects can be traced to inaccurate predredging assessment of the problem and to inadequate amounts of sediment removal (Brashier et al., 1973; Churchill et al., 1975; George et al., 1981). The need for accurate assessment of the problem cannot be overemphasized.

The most thoroughly documented long-term evaluation of lake dredging took place at Lake Trummen, Sweden. The lake has a history of receiving domestic and milling wastes since 1936. Sewage discharge to the lake stopped in 1959 after the flax-dressing plant closed and wastewater from the surrounding area was connected with a municipal treatment system. Despite the wastewater diversion, no apparent recovery of the lake followed. A limnological investigation of the lake in 1968 revealed that the upper 1 meter of sediment was extremely nutrient rich relative to that underlying it.

One meter of surface sediment was dredged from the main lake basin in 1970 and 1971. This removal increased the mean depth of the lake from 1.1 to 1.75 m and the maximum depth from 2.1 to 2.5 m. The total volume of the sediment removed was about 30 x 10^5 m^3. By any standard the lake was still extremely shallow and could have remained eutrophic except that the sediment skimming treatment reduced the phosphate phosphorus content in the surface sediment layer sediment from 2.4 to 0.1 mg $liter^{-1}$ (Sjön Trummen i Växjo, 1977).

The dredged material was partially disposed in shallow diked-off bays. The remainder went to upland diked ponds where return flow was treated with aluminum sulfate to reduce the total phosphorus concentration from about 1 mg $liter^{-1}$ to 30 µg $liter^{-1}$. Dried dredge material was sold as top soil dressing for about $2 (U.S.) m^{-3}.

Bengtsson et al. (1975) indicated that the role of the sediment in recycling nutrients was reduced substantially following dredging. The data in Figure 7 demonstrate an approximate 90 percent reduction of total phosphorus in the surface water of Lake Trummen after dredging (from 600 µg $liter^{-1}$ to a range of 70-100 µg $liter^{-1}$).

The significant nutrient reduction in the lake resulted in equally significant biological changes. The Shannon diversity index for phytoplankton rose from 1.6 in 1968 to 3.0 in 1973 (Cronberg et al., 1975). Secchi disc transparency went from 23 to 75 cm during the same period. The blue-green algal biomass was reduced dramatically and the nuisance species Oscillatoria agardii disappeared completely. Phytoplankton productivity went from a level of 370 g C m^{-2} in 1968-69 to about 225 g C m^{-2} in 1972-73.

The affect of dredging on the benthic community of Lake Trummen was negligible. A year after dredging tubificid oligocheates and chironomids were more numerous than before dredging, but the total number of benthic organisms changed little (Andersson et al., 1975). Rapid recolonization was attributed to the mobility and constant swarming of chironomids.

Surface sediment skimming at Lake Trummen was successful in rolling back the effects of eutrophication. The results have remained relatively constant for nine years, which attests to the thorough pretreatment evaluation and the rational plan for restoration. These

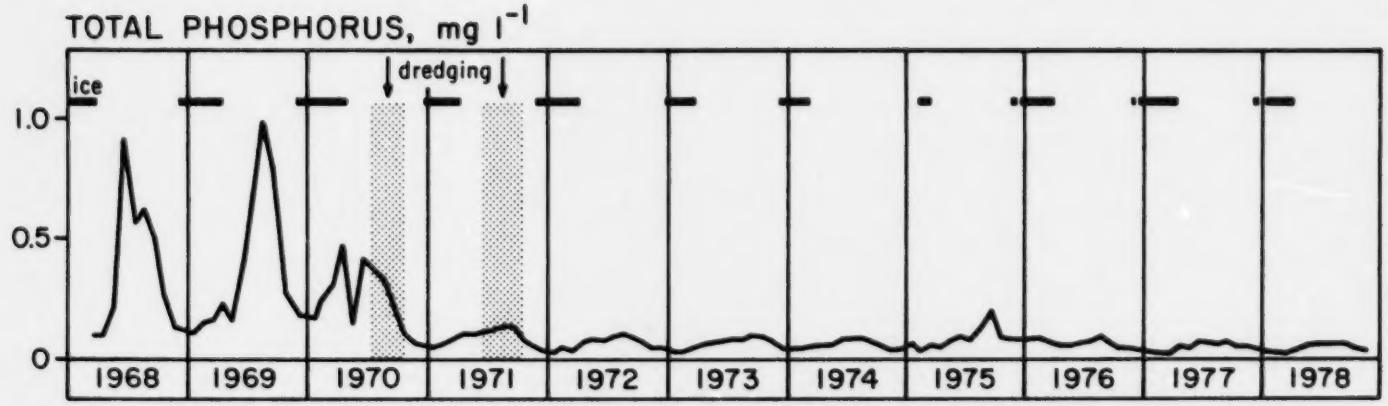

Figure 7. Total phosphorus concentraration in Lake Trummen, Sweden before and after dredging (courtesy of Gunnar Andersson, Department of Limnology, University of Lund, Lund, Sweden).

results are highly encouraging, because if surface sediment dredging is successful in a shallow lake like Trummen, it should also be successful in deeper ones with similarly enriched surface sediment.

Lilly Lake is a 37 ha closed basin lake in southeastern Wisconsin. Its agricultural watershed is only 155 ha. In 1977, shoaling had advanced to the point that the lake had a maximum depth of 1.8 m and a mean depth of only 1.4 m. The basin contained more than 10 m of partially decomposed plant materials. The Wisconsin Department of Natural Resources (1969) reported that chemical eradication and restocking of centrarchid and northern pike failed due to severe winter kill problems. The rate of basin infilling by sedimentation had reached 0.5 cm yr^{-1} (Dunst, 1981).

Restoration of Lilly Lake for fish management purposes was recommended by the Wisconsin DNR (1969). The plan called for deepening at least 10 percent of the basin to a depth of 6m. This required removing 665×10^3 m^3 of sediment.

Dredging began in July 1978 and continued until freeze-up in November. It began again in May 1979 and was completed in September. The dredged material was pumped approximately 3 km and disposed of in an abandoned gravel pit. Although the groundwater table rose temporarily due to this disposal, monitoring wells revealed no adverse impact on groundwater quality. Figures 8, 9, 10, and 11 show in-lake changes for selected variables before, during, and after dredging. Prior to dredging in 1977 the total inorganic nitrogen (TIN) concentrations were barely detectable. Although total phosphorus (TP) increased to more than 40 µg $liter^{-1}$ during July, August, and September it was not due to excessive phytoplankton concentrations as evidenced in Figure 10. The water quality *per se* of Lilly Lake was not exceptionally poor prior to dredging. However, water volume was reduced significantly due to the presence of macrophytes and partially decomposed macrophytes in the sediment.

Adverse, although not severe, short-term changes occurred during the active dredging period. TIN increased rapidly (Figure 8) when dredging began in July 1978, due mostly to the liberation of ammonium-nitrogen from the sediment (Dunst, 1981). It remained in excess of 3.5 mg $liter^{-1}$ during most of the 1978-1979 ice-cover period then declined steadily throughout the spring and summer.

TP concentrations behaved in a fashion similar to TIN, except there were minor peaks in TP during the summer of 1978. TP remained relatively high during the fall and winter of 1978-1979.

Phytoplankton responded in a predictable manner to the increased nutrient concentrations (Figure 10). The July-September average gross primary productivitity increased from 185 mg C m^{-3} day^{-1} in 1976 and 140 mg C m^{-3} day^{-1} in 1977 to over 1,000 mg C m^{-3} day^{-1} in 1978 (Dunst,

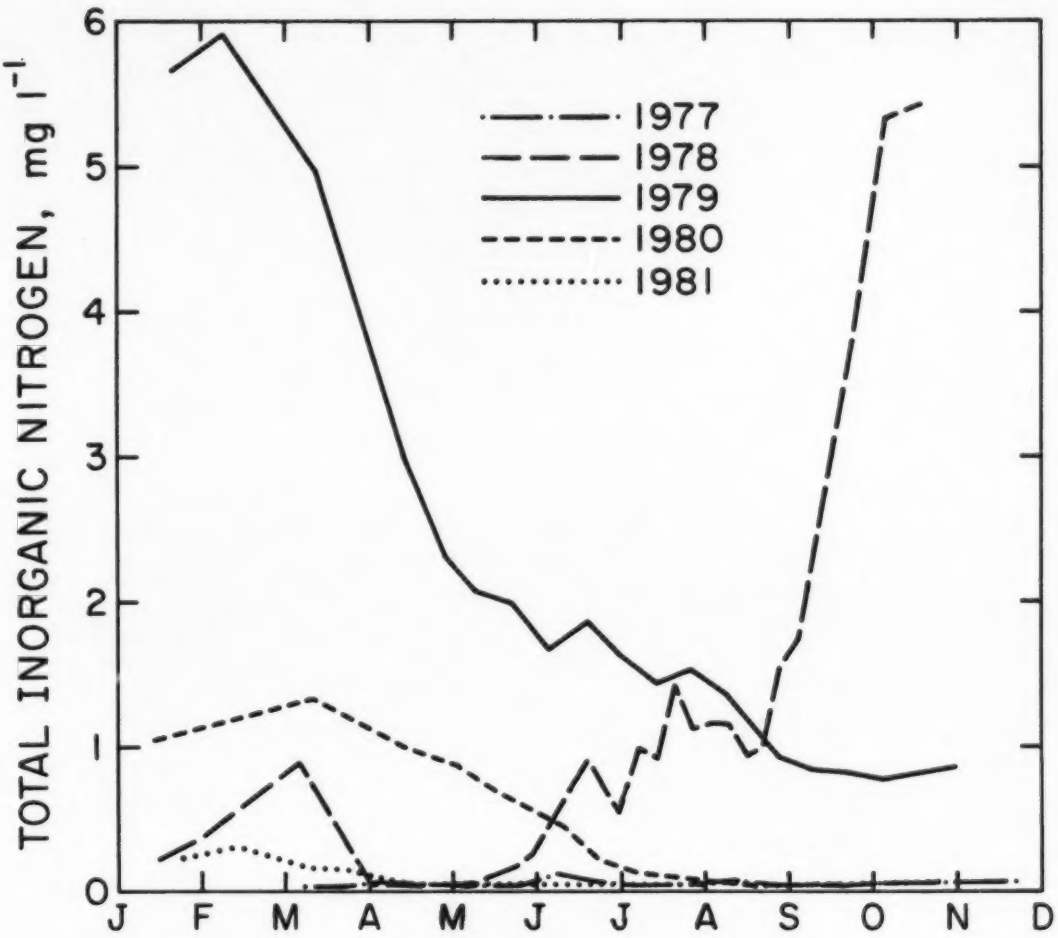

Figure 8. Total inorganic nitrogen in Lilly Lake, Wisconsin (data courtesy of Russell Dunst, Wisconsin DNR, Madison).

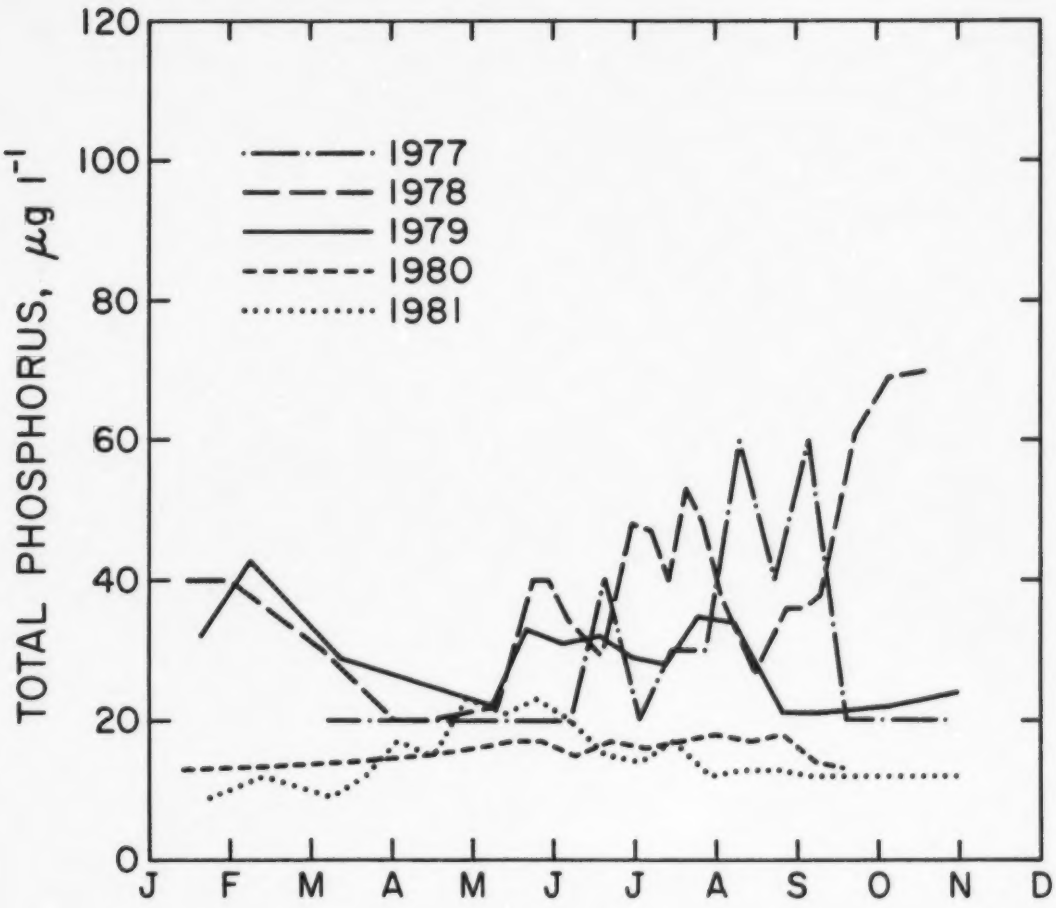

Figure 9. Total phosphorus in Lilly Lake, Wisconsin (data courtesy of Russell Dunst, Wisconsin DNR, Madison).

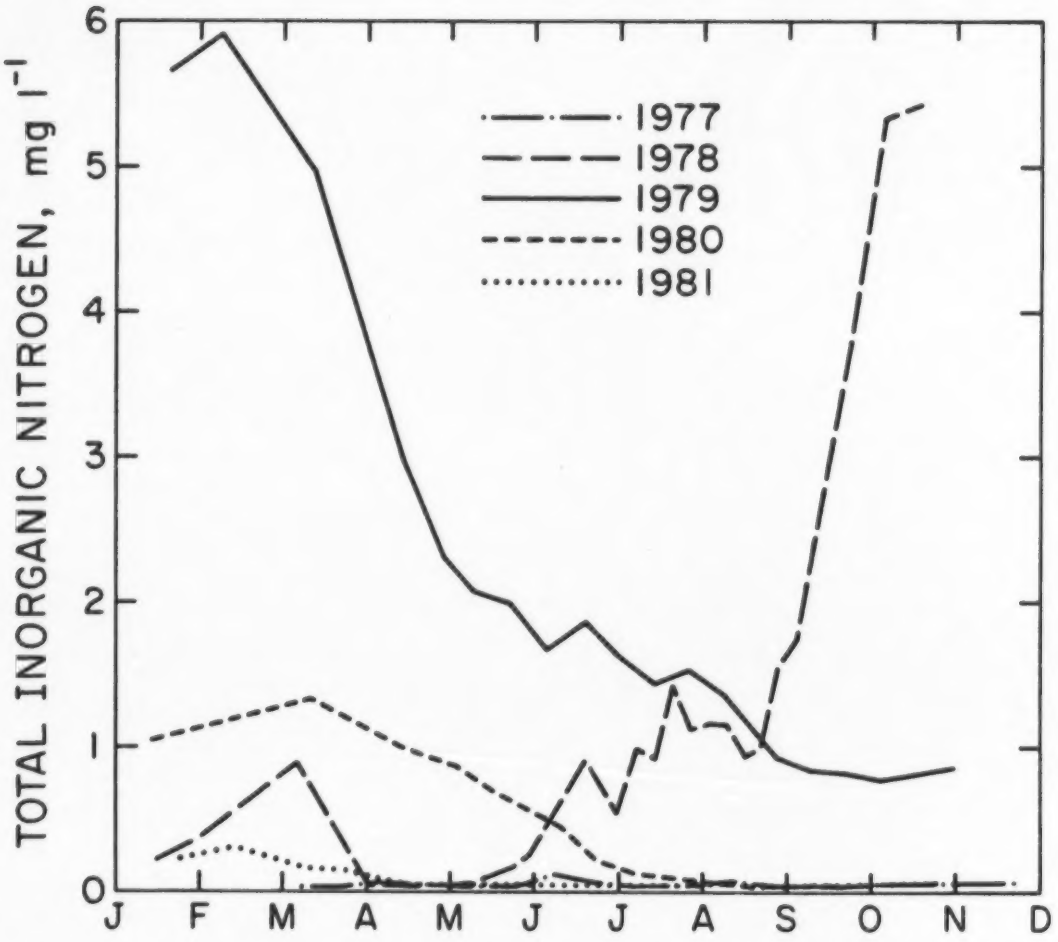

Figure 10. Chlorophyll a in Lilly Lake, Wisconsin (data courtesy of Russell Dunst, Wisconsin DNR, Madison).

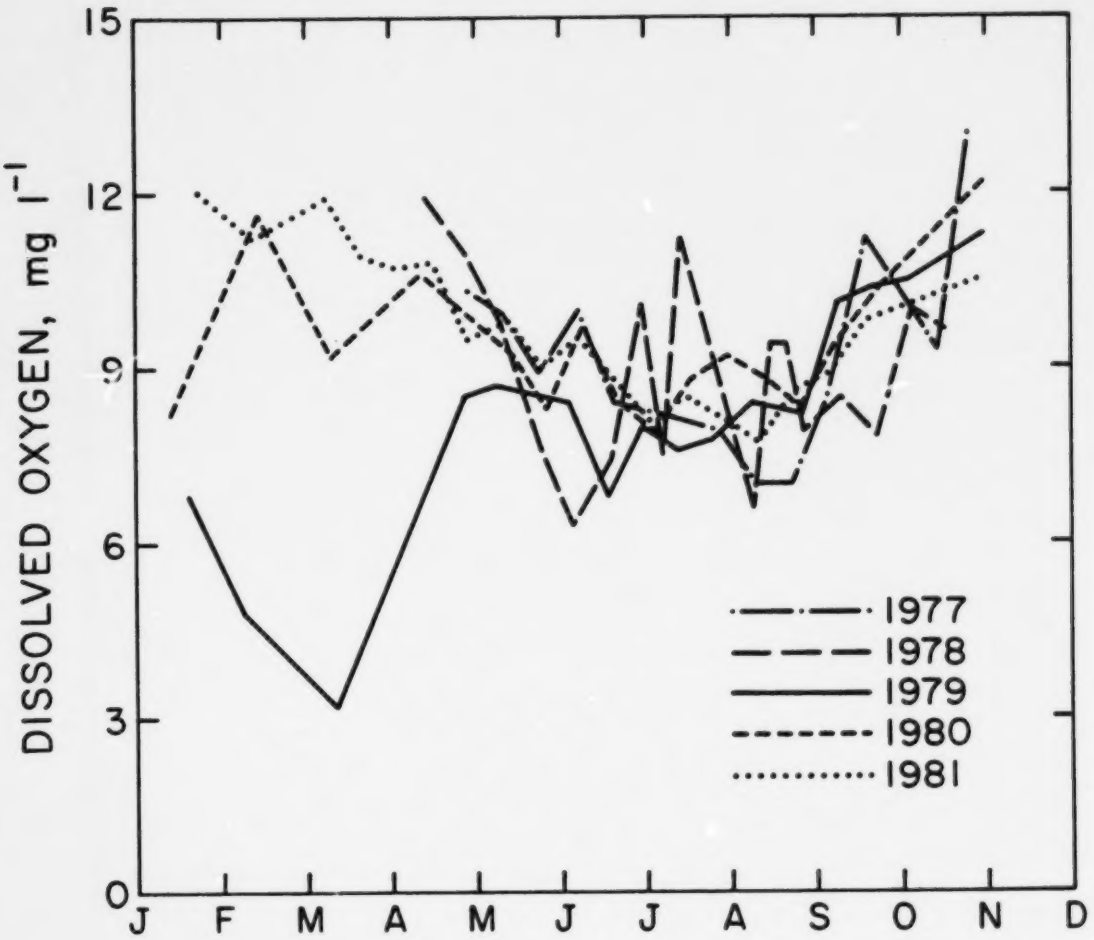

Figure 11. Dissolved oxygen in Lilly Lake, Wisconsin (data courtesy of Russell Dunst, Wisconsin DNR, Madison).

1981). Dissolved oxygen concentrations remained near saturation during most of the Lilly Lake project period. Except for the winter of 1978-1979 there were no signs of depressed values (Figure 11).

All of the above variables returned to near or below predredging levels when dredging ended in September 1979. The 1980 and 1981 TP concentrations were significantly lower than they were prior to or during dredging. Chlorophyll *a* concentrations were slightly higher in 1980 and 1981 than in the predredging year of 1977. Most importantly, the water storage capacity of the lake was increased 128 percent (Dunst, 1981) and the overall objective of increasing the recreational quality of Lilly Lake was realized. The two-summer inconvenience of dredging has resulted in what lake users hope will be a long-term benefit.

COSTS

The relevance of sediment removal cost comparisons is questionable because a large number of variables affect the cost figures. These include the type of equipment used, the project size (volume of material to be removed), availability of disposal area, the density of the material being removed, the distance to the disposal area, the ultimate use of the removed material, and a number of other factors. Data for 64 lake sediment removal projects in the United States indicated a cost range from \$0.24 m^{-3} to \$14.00 m^{-3} (Peterson, 1982). Given the above variability, an average cost figure is meaningless; however, hydraulic dredging costs ranging from \$1.25 m^{-3} to \$1.75 m^{-3} are relatively common and probably can be considered "reasonable." If toxic substance contaminated sediment is encountered and special dredges and/or treatment methods are required (Matsubara, 1979; Koba *et al.*, 1975; Barnard and Hand, 1978), dredging costs may exceed \$25.00 m^{-3}. In general, the per unit volume cost of sediment removal will be inversely related to the total volume of material removed. Any time dredged material is of sufficient quality for use as potting or top soil dressing as was done at Lake Trummen, Sweden (Sjön Trummen i Växjö, 1977) and Nutting Lake, Massachusetts (Worth, 1981) the overall project costs might be reduced significantly.

SUMMARY

The reasons for dredging lakes are to deepen, limit nutrient recycling, reduce macrophytes, and to remove toxic substances. Case histories of lake dredging projects to date reveal that while some adverse impacts to the lake do occur during dredging, most are of short duration and the end result warrants the short term impacts.

There is little doubt that dredging can be a successful lake restoration technique if the project is properly designed and implemented. Successful examples of both surface sediment skimming and deep (6 to 8 m) dredging can be cited. Emphasis should be placed on proper pre-treatment evaluation and execution of thorough implementation plans.

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